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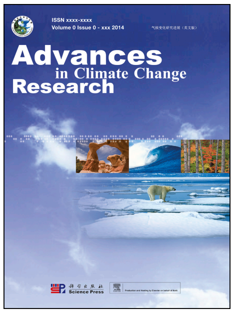

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Climate services for addressing climate change: Iindication of a climate livable city in China

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ABSTRACT

China, like many countries, is under great pressure to reduce climate change and adapt to current situations while simultaneously undertaking economic development and transformation. This study takes advantage of climate opportunities and provides a new concept and mode of urban climate services in order to address climate change. Eighteen indicators based on climate and climate-related variables were used to provide an assessment, in the form of an index, of how livable a city is depending on prevailing climatic conditions. The resulting index can also be used to investigate how recent and future changes in the climatic conditions could affect livability. All Chinese cities and regions share the common goals of promoting low-carbon development, improving resilience against climate change, and integrating economic growth with climate actions. Climate services have been developed in China to provide decision-makers this measure of livability. Such a move facilitates sustainable development alongside economic growth by aiding government efforts in climate adaptation and low-carbon development. Our approach represents multidisciplinary and demand-driven research on adaptation to and the impacts of regional climate change, thereby transforming climate science into a climate service and ensuring that climate information can be provided in a scientific, practical, and customized way for policy-makers. The outputs can be used locally to take concrete climate actions and integrate climate services into decision-making processes.

Keywords: Climate services; Addressing climate change; Climate livable city; China

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1. Introduction

In some ways, the climatic conditions in a given region or locality can be considered natural resources that shape not only the world's ecosystems but also humankind's socioeconomic conditions. Changes to the climatic conditions have been proven to have visible impacts on ecosystems and socioeconomic development (IPCC, 2012, 2014a). Our ability to address risks and opportunities related to climate change is taking on an increasingly important role in our well-being. In order to jointly deal with the threat of a changing climate, the international community has reached the Paris Agreement, which has identified long-term goals related to resolving the issues related to climate change. Through this agreement, modern society is bound to accelerate the transition toward a low-carbon economy (UNFCCC, 2015).

Addressing climate change is not only about reducing greenhouse gases but also taking proactive measures to adapt to a changing climate and to alleviate the negative effects and key risks of this phenomenon by better managing and altering human activities (IPCC, 2014a, 2014b). After the signing of the Paris Agreement, local governments in China now face the urgent task of transforming their economies toward low-carbon growth. At the same time, they are also facing great pressure to adapt to climate change. Hence, striving to achieve sustainable development in harmony with the local climatic conditions (considered in this study as 'climate resources'") has become a new driver for local governments in China.

One essential component of sustainable development is the provision and use of climate information that can help decision-makers and policy-makers better address climate change (Hewitt et al., 2012; Vaughan et al., 2014; Brasseur et al., 2016; Lourenco et al., 2016; Hewitt et al., 2017). Climate services refer to the process in which climate information is obtained and provided with the goal of addressing the needs of decision-makers and policy-makers. The services aim to better equip society to manage risks and maximize opportunities brought about by climate change. In recent years, climate services have attracted significant global attention (Lemos et al., 2012; Vaughan et al., 2014; Brasseur and Gallardo, 2016; Lourenço et al., 2016; Wang et al., 2020). However, only a few studies have investigated the use of climate information as a resource to support low-carbon and sustainable development through the maximization of climate opportunities (Peng et al., 2010; Li et al., 2016; Shi et al., 2019; Zheng et al., 2019).

Therefore, in the current study, we use climate-related variables to define a measure—in the form of an index—of how livable a city is based on prevailing climatic conditions. The proposed livability index is then used to estimate how recent and future changes in climate conditions affect livability. All Chinese cities and regions share the common goals of promoting low-carbon development, improving resilience against climate change, and integrating economic growth with climate actions. In relation to these goals, climate services have been developed in China to provide this measure of livability to decision-makers. Such services facilitate sustainable development alongside economic growth by aiding efforts in climate adaptation and low-carbon development and by investigating how livable cities could be considering future climatic conditions. The outputs can be used locally to take concrete climate actions as well as integrate climate services into decision-making. This study also elaborates on China's experience and deficiencies in climate services meant to address climate change and explores various ways to better enable climate services to deal with climate change.

2. Indication of climate livable city

2.1 Definition and goals

While there are several important factors affecting how livable a city is, such as natural, social, and economic factors (Lennard, 1997; Douglass, 2002; Evans, 2002), the current study focuses on climatic factors. Whether or not the living environment is comfortable is one of the important criteria for individual and industrial stakeholders to evaluate the livability of cities (Li et al., 2003; Li et al., 2016). The concept of 'livability' here is focused on a city being suitable for human habitation based on prevalent climatic conditions and other climate-related environmental conditions. In light of climate change, climate-related indicators of livable cities have attracted increasing attention from scholars in recent years (Li et al., 2003; Zhu et al., 2014; Scott et al., 2016). Methods for judging the advantages and disadvantages of climatic conditions include the comprehensive evaluation and climate index methods (Yan et al., 2013; Li et al., 2016; Shi et al., 2019).

China's climate livability index for cities is derived from several quantitative assessment indicators, such as climate risk, climatic conditions, and the ecological environment, and is developed based on previous studies (Fig. 1). The present study illustrates how essential local climatic conditions can be used to develop a relatively simple and easy-to-understand index for various stakeholders. The proposed climate livability index, described below, is provided as a climate service based on the scientific and authoritative assessment of local climatic conditions and the associated ecological environment.

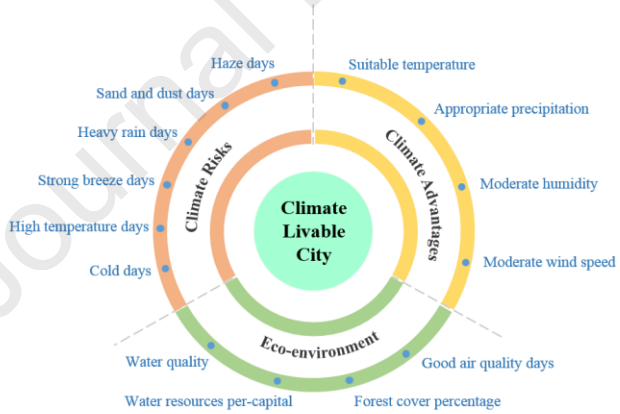

Fig. 1 Assessment indicators of a climate livable city

One important goal of this new climate service is to contribute to addressing climate change by providing an important measure enabling meteorological departments to help the service recipients understand the local climate and exploit the climate conditions as a resource. Such a measure can also help assess how livable the climatic conditions are; promote green, sustainable, and low-carbon development; and improve adaptation to climate change by raising the awareness of the government, relevant stakeholders, and the general public.

2.2 Climate livability index

The indicators are related to humans' physiological and psychological links to climatic conditions (Li et al., 2003; Shi et al., 2019). For example, the comfortable temperature of normal human skin is about

15–25 °C. When the temperature is below 15 °C, the human body would feel cold, whereas when the temperature exceeds 25 °C, the human body would feel hot (Li et al., 2016). In the proposed index, the indicators include the number of days per year with suitable temperature (15 °C ⩽ daily mean temperature ≤ 25 °C), the number of days per year with suitable humidity (50% ≤ daily relative humidity ≤ 80%), number of days per year with suitable wind speed (0.3 m s^{-1} ≤ daily mean wind speed ≤ 3.3 m s^{-1}), and annual precipitation, precipitation variability coefficient, mean daily temperature range, mean relative humidity, and mean wind speed. On the basis of the Specification for Climate Resource Assessment: Climate Livable Town (CMA, 2020), each indicator is divided into the following categories: 'excellent,' 'good,' and 'fair' (Table 1).

Table 1 Indicators used to evaluate a climate livable city

Indicator	Sub-indicator	Classification of indicator level		
		Excellent	Good	Fair
Climate endowment	Number of days with a suitable temperature (d)	⩾150	[120, 150)	<120
	Daily temperature range (°C)	[8, 10]	[6, 8) or (10, 14]	<6 or >14
	Annual precipitation (mm)	[800, 1200]	[400, 800] or (1200, 1600]	<400 or >1600
	Precipitation variability coefficient	≤0.18	(0.18, 0.22]	>0.22
	Annual mean relative humidity (%)	[65, 75]	[50, 65) or (75, 80]	<50 or >80
	Number of days with a moderate relative humidity (d)	⩾210	[180, 210)	<180
	Annual mean wind speed (ms^{-1})	[1.5, 2.5]	[1, 1.5) or (2.5, 3.3]	<1 or >3.3
	Number of days with a suitable wind speed (d)	⩾300	[240, 300)	<240
Climate risk	Number of days with a high temperature (d)	⩽3	(3, 15]	>15
	Number of cold days (d)	⩽5	(5, 60]	>60
	Number of days with heavy rain (d)	⩽3	(3, 10]	>10
	Number of days with a strong breeze (d)	⩽3	(3, 15]	>15

Eco-environment	Number of days with sand and dust (d)	⩽1	(1, 3]	>3
	Number of days with haze (d)	⩽1	(1, 10]	>10
	Percentage of days with good air quality (%)	⩾90	[80, 90)	<80
	Percentage of forest cover (%)	≥50	[30, 50)	<30
	Water resources per capita (m^3)	≥2000	[1000, 2000)	<1000
	Water quality	I	II	III

The climate livability risk indicates the negative impacts of climate on livability and other possible hazards. According to the Specification for Surface Meteorological Observation (CMA, 2003), the numbers of days per year with cold days (daily minimum temperature ⩽ −10℃), with heavy rain (daily precipitation ⩾ 50.0 mm), with strong winds (maximum daily wind speed ⩾ 10.8 m s^{-1}), with dust storms and haze, and with uncomfortably high temperature (daily maximum temperature ≥ 35 ℃) are used as individual indicators to evaluate the climate livability risk of a place. The evaluation levels of indicators are divided into 'low,' 'medium,' and 'high,' corresponding to the levels of climate-related suitability for living, namely, 'excellent,' 'good,' and 'fair.'

The climate livability eco-environment indicator is based on water quality and quantity, air quality, and the amount of forest surrounding the city. Meanwhile, forest coverage, the percentage of days with good air quality (MEP, 2012), water resources per capita, and water quality of major rivers and lakes are used as individual indicators to evaluate the climate livability eco-environment of a place. Each indicator is divided into 'excellent,' 'good,' and 'fair.'

To derive an overall index of climate livability, the numbers of indicators assessed as excellent and good are calculated for each city considered. Cities are defined as having good livability if they achieve rates of more than 50% for excellent, and combined good and excellent rates of over 80% (CMA, 2020).

2.3 Data

The 1961–2017 climate observation data from Jiande city, which were used as a case study, were extracted from the Dataset of Daily Surface Observations Collected at Chinese Surface Meteorological Stations published by the National Meteorological Information Center of China, Meteorological Administration (Ren et al., 2012). Data on the $PM_{2.5}$ concentrations from 2014–2017, as well as water quality and forest coverage in Jiande for the year 2017, came from the respective local governmental agencies.

3. Case study: Jiande city in Zhejiang province

3.1 Assessment of climate livability

In this section, we take Jiande city in Zhejiang province as an example to demonstrate how climate service has helped local governments deal with climate change using the climate livability index. Jiande city (29°12′20°–29°46′27″N, 118°53′46″–119°45′51″E), located 108 km away from Hangzhou city, has geomorphological characteristics of eight mountains, one water, and one farmland. The territory is very rich in water resources with the presence of the Xin'anjiang Reservoir—the water source of the famous Nongfu Mountain Spring. In 2017, the Jiande municipal government was the first to ask the National Climate Center (NCC) for a climate livable city rating.

Based on the method described in Section 2.2, the NCC used observations to assess the 18 indicators, of which 16 were determined as good to excellent and 10 were excellent (Table 2). Thus, Jiande became the first city in China to be verified as having good climate conditions for livability in 2018.

Table 2 Climate livable city assessment results for Jiande city, Zhejiang province

Sub-indicator	Indicator value	Classification
Suitable temperature days (d)	131.3	Good
Daily temperature range (°C)	9.5	Excellent
Annual precipitation (mm)	1580.4	Good
Precipitation variability coefficient	0.16	Excellent
Annual mean relative humidity (%)	78.5	Good
Moderate relative humid days (d)	187.9	Good
Annual mean wind speed (m s^{-1})	1.2	Good
Proper wind speed days (d)	341.5	Excellent
High temperature days (d)	37.5	Fair
Cold days (d)	0	Excellent
Heavy rain days (d)	17.7	Fair
Strong breeze days (d)	2.1	Excellent
Sand and dust days (d)	0.2	Excellent
Haze days (d)	3	Good
Good air quality days (%)	91	Excellent
Forest cover percentage (%)	76.2	Excellent
Water resources per capita (m^3)	3646	Excellent
Water quality	Ⅰ	Excellent

Jiande has a subtropical humid monsoon climate. Owing to its geographical location and topography, the city's climate-related suitability for living is very favorable. In particular, the number of days with suitable wind speeds, temperatures, and precipitation is much higher than the national average. Compared with surrounding cities, especially those in the same latitude, Jiande also has warmer winter and cooler summer seasons. Furthermore, it has a longer spring as well as winter and summer seasons that come relatively later. Although high temperatures exist in the summer, thanks to the local effect of the Xin’anjiang Reservoir on the microclimate, the degree to which daily temperatures vary during this season remains pleasant (NCC, 2018). Thus, our analysis based on the Meteorological Disasters Database reveals that Jiande has not been greatly affected by meteorological disasters (Jiao et al., 2015). Moreover, with the combination of favorable atmospheric conditions for dispersing air pollution and effective government prevention and control measures, Jiande’s average $PM_{2.5}$ concentration from 2014–2017 was just 40.5 $\mu g\ m^{-3}$ and has continued to decrease since then. Furthermore, air quality was excellent and good in 353 d, accounting for 97% of the year and ranking first in Hangzhou (Fig. 2). The forests surrounding Jiande in 2017 reached over 176,400 hm^2, indicating a forestry cover of 76%, which is 15% higher than the average for Zhejiang province and 54% higher than the national average for Chinese cities. There is plenty of surface water in Jiande city, and the water quality of the Xin’anjiang River is outstanding, having reached the national first-class drinking water standard.

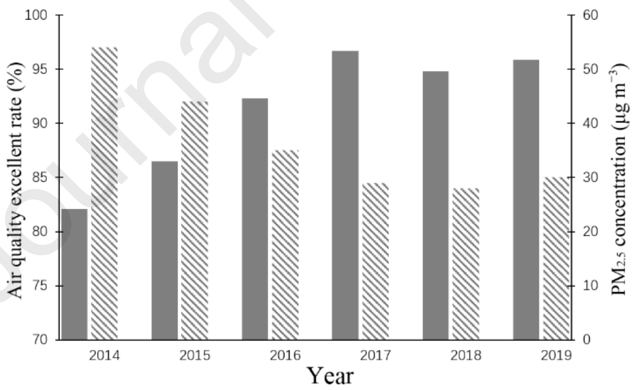

Fig. 2 Percentage of excellent air quality and $PM_{2.5}$ concentration in Jiande city, Zhejiang province from 2014 to 2019

3.2 Impacts of climate change

Global climate change has impacted many aspects of the human habitat and environment (Scott et al., 2012; Wang et al., 2017; Dube et al., 2018; Yin et al., 2018). In this work, we assess how changes in climatic conditions affect the climate livability in Jiande by analyzing the observed climate data throughout the observational period of 1961–2017 (Ren et al., 2012) and the projected future climate change downscaled to a horizontal resolution of 6.25 km for 1986–2005 (Han et al., 2019). The long-term trend in annual average temperature in Jiande increased at a rate of 0.10 ℃ per decade, while the annual precipitation increased at a rate of 46 mm per decade during 1961–2017 (Fig. 3a–b). As shown in the corresponding images in Fig. 3c–e, the number of days with suitable humidity, temperature, and the wind speed increased at a rate of 1.2, 3.9, and 9.3 d per decade, respectively. The numbers of high- and low-temperature days both decreased at rates of 1.2 and 3.3 d per decade, respectively (Fig. 3f–g), while the number of days with heavy rains increased at a rate of 0.5 d per decade (Fig. 3h). On the basis of these results, we can say that, on the one hand, these lead to an increase in the number of comfortable conditions days, particularly in winter. On the other hand, these can increase heat stress and heavy rainfall risk during summer.

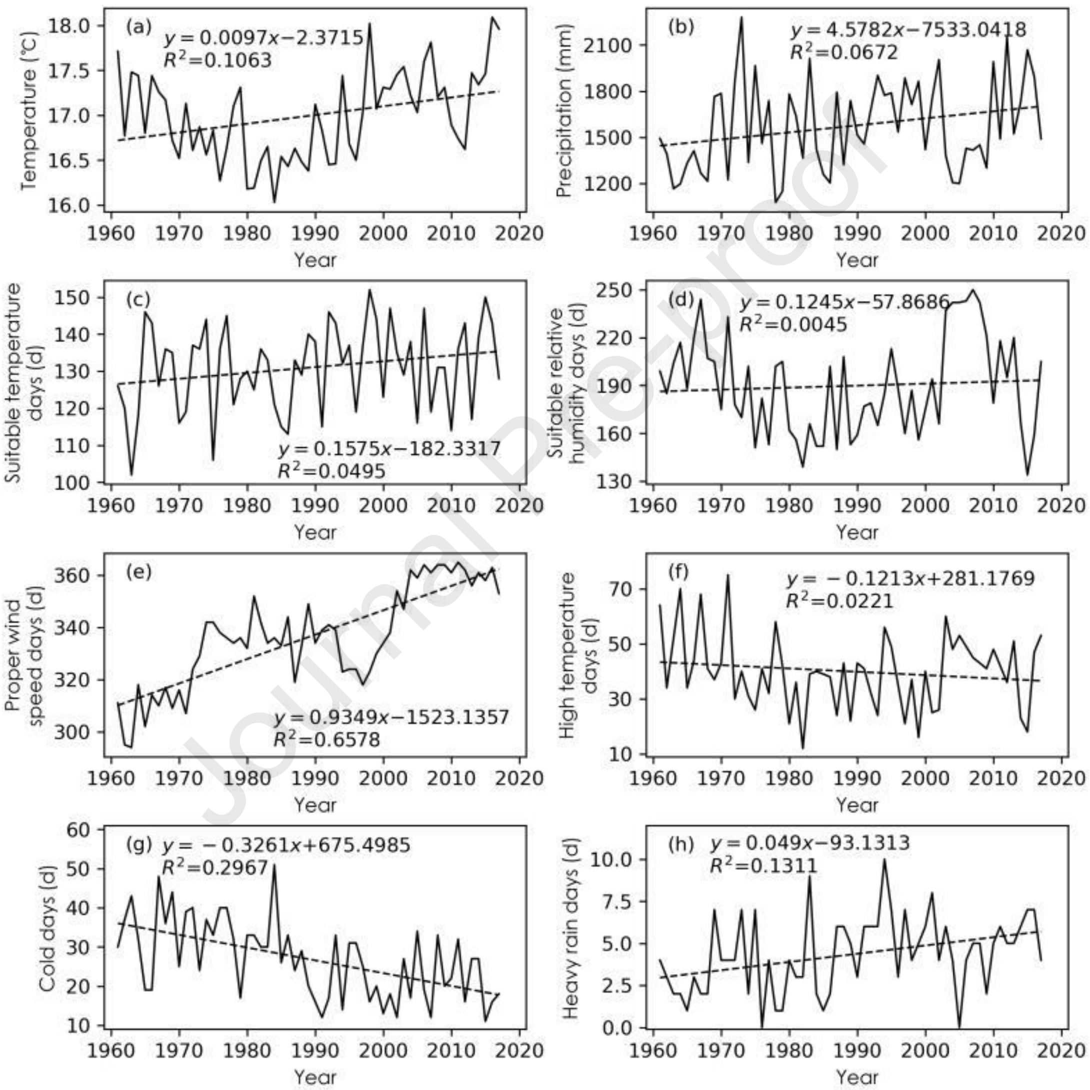

Fig. 3 Changes of climate elements and the linear trends in Jiande city, Zhejiang province from 1961 to 2017

Based on the climate change projection data (Han et al., 2019), it is estimated that the average annual temperatures in Jiande city by 2050 and 2100 could increase by 1.3 °C and 2.2 °C, respectively (Fig. 4a). The annual precipitation is projected to increase in future periods, but with sizable variability with the magnitudes not exceeding 6% and 12% by 2080 and after 2080, respectively (Fig. 4b). The projected precipitation change shows interdecadal variations, but with a long-term trend of 0.8% per decade.

Furthermore, in the future, both the extreme high-temperature events and heavy precipitation events are projected to increase (Fig. 4c–d). Specifically, by 2050, the numbers of tropical nights (TR) and heat days (HD) are both projected to increase by about 20 d; by 2100, the TR and HD are projected to increase by 25 and 30 d, respectively.

Similar to the annual precipitation, the changes of extreme precipitation in the future also show interdecadal fluctuations. The number of very heavy precipitation days (R20) is not projected to change much before 2080, and the change fluctuates within ±1 d. After 2080, it is projected that there would be a slight increase in R20 of up to 3 d. The projected maximum 5-d precipitation (Rx5day) shows a rising long-term trend, increasing from about 15 mm before 2060 to about 40 mm by the end of the 21st century.

All of the above changes are expected to have an impact on the future comfortability of the condition in the city. Especially, extreme high-temperature and heavy precipitation events could result in more risks to the livability in Jiande.

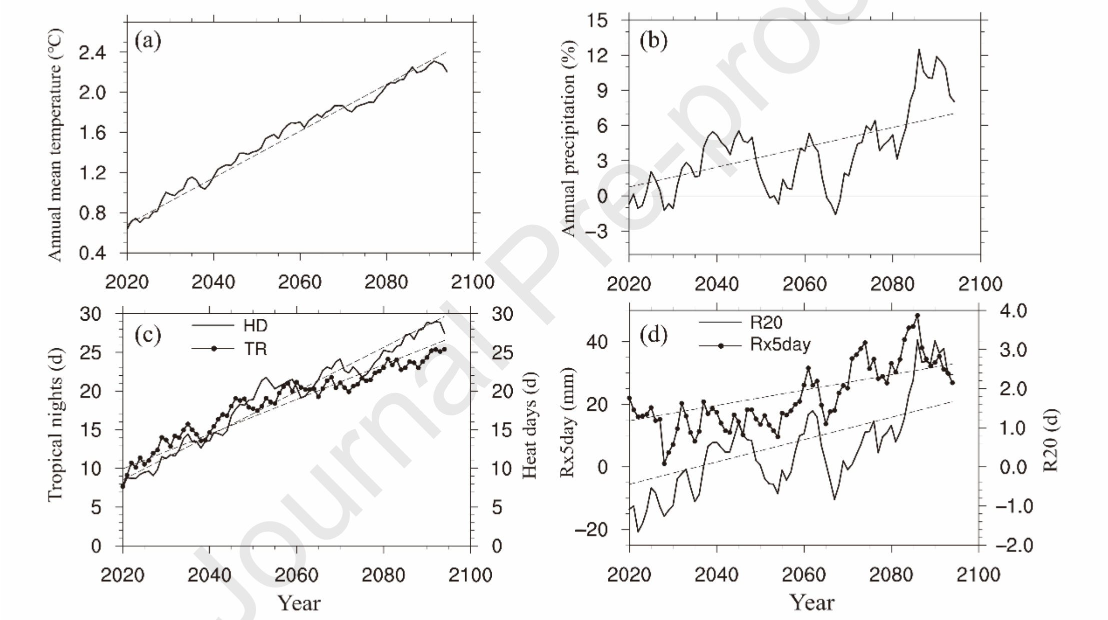

Fig. 4 Projected changes in the area averaged annual (a) mean temperature, (b) precipitation, (c) tropical nights (TR) and heat days (HD), and (d) R20 and Rx5 d (The values are smoothened by a 9-year running mean. The dash lines indicate linear trends)

3.3 Effectiveness of the climate service

With the climate service provided by the NCC, Jiande currently has the title of China's climate livable city and has been widely hailed by the public as a result. On the day the assessment report was released, the WeChat news had over 100,000 clicks within an hour (https://mp.weixin.qq.com/s/ejm8jfXtZq4NkfFT0y5-Cw). In this section, we summarize three positive impacts of this climate service as an indication of how livable a city's climatic conditions are.

First, the municipal government has promoted green and low-carbon development in order to fully maximize its favorable climatic conditions. The Jiande government has designed a city logo with

'Livable Jiande' as the major element, which has been widely applied in stationeries, image promotional materials, major events, urban landscapes, as well as public buildings and transportation facilities. Since then, a series of activities with the theme 'Livable Jiande' have been conducted to boost the city's popularity and reputation and to translate its climatic advantages into economic drivers. After the attainment of this honor in 2018, for the first time in 2019, over 10 million tourists visited Jiande. This generated revenues of up to 13.5 billion CNY, up by 24% compared with the previous year, thus indicating the fastest growth during the past six years. Moreover, due to the favorable climate and ecological conditions, many green-development projects, such as Huiquan Health and Welfare Center, Gantan Hualing Health, and Shouchang Hengda Hot Springs Recreation Town, have been established in Jiande, giving strong impetus to its green economy.

Second, the awareness by the government and the public of climate, ecological, and environmental issues has been greatly improved. After being officially recognized as a climate livable city, the Jiande government has continued to assess its favorable climate resources by carrying out research on climate resources for the tourism and agriculture industries. For example, farmers' incomes have increased through the division of regions for the cultivation of Jiande Bao tea (http://www.jiande.g.,ov.cn/art/2019/2/28/art_1295246_30571195.html). Meanwhile, greater efforts have been made to protect the environment and safeguard climate livability. Since then, it is considered that the environment has become more livable after Jiande was granted the honor. In fact, the rate of excellent and good air quality exceeded 95% in 2018 and 2019, with the annual average $PM_{2.5}$ concentration of below 30 μg m^{-3} (Fig. 2). In the realm of urban and rural development planning, greater consideration is now given to the risks of climate change. Engineering measures have been made to deal with extreme weather and climate events.

Third, the government has taken initiatives to adapt to climate change by building its response capacity against disasters due to extreme climate events and implementing enhanced early warning services for each town in the region. The conclusions and recommendations on climate risks in the assessment report from NCC, which is part of the climate service, have persuaded Jiande city officials to take measures and build an ecological and climate monitoring network. Since then, the city now has 69 regional automatic stations, five negative oxygen ion monitoring stations, one haze monitoring station, and one acid rain observation station. Furthermore, Jiande has promoted the full coverage of real-time monitoring and early warning of meteorological disasters as well as encouraged data sharing with monitoring stations responsible for water conservancy, environmental protection and forestry conservancy.

3.4. Deficiencies of the climate service

The climate service approach has been widely recognized by the society for addressing climate change and supporting economic transformation and development; furthermore, China's climate livable city index meets the needs of local governments to promote low-carbon development and to assess and cope with climate change (http://www.gov.cn/xinwen/2018-12/18/content_5349824.htm). However, the climate service approach has the following broad deficiencies, as described below.

First, the Climate Livability Assessment report of Jiande city analyzes the impacts of climate change on the climate livability in the city from the observed climate changes and future projections. However, this may not be enough. Furthermore, it is difficult to project the impact of climate change on climate livability indicators based on careful consideration of future regional socioeconomic development scenarios. For example, will Jiande still be a climate livable city in the future? How will it adapt to the increased risk of extreme high temperatures and extreme precipitation in the future? These questions certainly require further investigation.

Second, climate information for use in mitigating risks and enhancing resilience can only be truly valuable when it is integrated into specific actions to deal with climate change (Asrar et al., 2012). In other words, climate services should be closely connected with the actual decision-making needs, so that such services can truly reflect and benefit from the value of climate information being offered. Moreover, we found that the relevance of climate change research and its usability in decision-making needs to be improved. For example, the measures for Jiande to adapt to climate change are relatively macro, and the practical problems are not well targeted, especially in the fields of energy, water resources, agriculture, and infrastructure construction. This is because there is currently insufficient research and knowledge on the impact of and adaptation to climate change at the city scale. Thus, this topic requires further study. Research on regional climate change impacts and adaptation must be strengthened. Moreover, it should be guided by the improvement of society's ability to respond to climate change, thus facilitating the transformation of climate science into climate services for decision-making.

Third, the ability of climate services, especially for urban environments, to respond to issues and challenges related to climate change must be improved. For example, it is difficult to accurately depict Jiande's unique climate resources due to the low resolution of regional climate models and the low density of climate and environmental observations. Related to this, the scientific evaluation and the management process for climate livable cities must be further improved. In addition, climate services must be integrated across disciplines, thereby requiring collaborations among government decision-making agencies, environmentalists, climatologists, sociologists, and economists, particularly in designing and producing climate services.

4. Summary

China, like many countries, is under great pressure to mitigate and adapt to climate change while simultaneously striving to achieve economic transformation and development (Chao et al., 2014; Zhai et al., 2018). As presented in the current study, the different climatic conditions, both at present and in the future, can translate into varying livability conditions within cities and regions. However, all Chinese cities and regions share the common goals of promoting low-carbon development, improving resilience against climate change, and integrating economic growth with climate actions. Related to these, climate services have been proven to play an essential role in promoting climate change adaptation (Scott et al., 2011; Vaughan et al., 2014). Moreover, they are increasingly used to manage climate risks and seize any climate-related opportunities to promote sustainable economic and social development (Prokopy et al., 2017).

In today's rapid development and urbanization against the backdrop of climate change, there is a need to obtain climate information that is targeted and accessible and can be translated into actionable goals by relevant decision-makers (Lemos et al., 2012; Hewitt et al., 2017; Rowan et al., 2019). Hence, the current study provides a demonstration of urban climate services by proposing a new concept and mode of urban climate services for sustainable development, thus contributing to the goals of improving urban resilience and mitigating climate change. In the current study, the proposed climate livability index provides a useful illustration of how local climatic conditions can be used to develop a simple and easy-to-use index for a range of interested stakeholders. However, it must be noted that the index has been developed for China. Thus, countries with different climatic and socioeconomic conditions may need to develop and define their own criteria for climate livability that are suitable to their particular conditions. Moreover, further works should also consider other factors, such as outdoor thermal comfort, human bio climates, the potential of people to acclimatize, as well as other socioeconomic factors affecting livability. Therefore, the proposed indicators are just a preliminary step and require further improvement.

Finally, the climate services can popularize scientific knowledge on climate change, enhance the whole society's awareness of climate change, promote interdisciplinary integration, strengthen communication with users in order to understand their needs and gain their feedback, and improve the relevance and usability of climate services. We believe that scientific, readily available, and tailor-made climate services will greatly improve the link between climate information and government decisions.

Declaration of competing interest

The authors declare no conflict of interest.

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Climate services for addressing climate change: the indication of climate livable city in China

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Conflict of interest

The authors declared that they have no conflicts of interest to this work. We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.